

Integrating Language and Cognition in Grounded Adaptive Agents
EOARD Grant: FA8655-05-1-3060

Principal Investigator: Professor Angelo Cangelosi, University of Plymouth
Student employed: Mr. Vadim Tikhanoff

Final Report

PERSONNEL AND COLLABORATORS

The project started on the 1st of November 2005. The PhD student employed on the grant was Vadim Tikhanoff. Professor Angelo Cangelosi, Principal Investigator (PI), is also the student's first supervisor (Director of studies). Dr. Tony Belpaeme, from Plymouth University, is the second supervisor of the PhD student.

From the beginning of the grant we have closely collaborated with Dr. Leonid Perlovsky, who was a named collaborator in the proposal. In addition, we are collaborating with Prof. Fontanari, who holds another EOARD grant on a similar topic. This has been a very successful and productive collaboration and is reflected in the publication of a joint publication.

OBJECTIVES AND ACTIVITIES

The tables below provide an overview of the original objectives and the list of models and simulation experiments carried out during the project. More details on the actual simulation results are described in the enclosed report, in the publications, and in the project website. **Note that text in bold refers to the work produced between April and October 2006 (i.e. after submission of interim grant report). A detailed description of the new simulation setup and results is enclosed at the end of this document.**

Original Objectives	Activity
1. To adapt the MFT algorithm for the acquisition of linguistic, cognitive and sensorimotor abilities in adaptive agents	1.1 The original MFT algorithm has been extended: (a) to deal with multi-feature representation of objects (see simulations in 3.2) (b) to model the acquisition of words (see simulations in 3.3); (c) to scale up lexicon and model the combination of words to express complex/composite actions (see new simulations in 4.4-4.6)
2. To design and implement a computer simulator for linguistic agents with MFT controller	2.1 Tikhanoff has extended the original cognitive robotics simulator, originally developed by Hourdakis & Cangelosi, to deal with multiple objects and actions. This has been developed in C++ with the use of ODE libraries for physics routines and OpenGL for graphics. 2.2 Simulations on the MFT algorithm were first developed in Matlab, and then implemented in C++. This permitted the easy integration with the robotics simulator. 2.3 The robotic and MFT simulator has been extended further to include experiments on multi-stage learning of action and words. This for example permits the acquisition of basic actions, and their name, and the subsequent combination to produce complex actions. (see simulation experiments in 4.4-4.6) 2.4 During the Robotics Summer School (July 2006) the multi-dimensional MFT algorithm was modified and tested on a 23 degree of freedom humanoid robot. This successfully produced the categorization of actions of the real robot.
3. To execute a series of simulation experiments on the integration of language and cognitive abilities in collaborative tasks (e.g. object manipulation and navigation tasks)	3.1 We first replicated the simple version of the MFT algorithm initially proposed by Fontanari & Perlovsky (2005 KIMAS Conference) to model category formation for symbol grounding. 3.2 We have successfully extended the MFT to deal with multi-feature object classification, which is typical of our cognitive robotic model in which we have multiple features to presented objects and action. Results presented in the ICANN06 paper. 3.3 We have started to adapt the multi-feature MFT algorithm to model the acquisition of words. Initial simulations were done at the workshop in Brazil and presented at ICANN2006 conferences.

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13. SUPPLEMENTARY NOTES						
14. ABSTRACT In future, machine agents will be able to communicate among themselves and with humans with the flexibility and complexity of human language. Leonid Perlovsky proposed Modeling Field Theory (MFT) as a new method for overcoming the exponential growth of combinatorial complexity (CC) in computational intelligent techniques currently used in cognitive systems design. MFT uses fuzzy dynamic logic to avoid CC and computes similarity measures between internal concept-models and the perceptual and linguistic signals. More recently, Perlovsky (2004) has suggested the use of MFT specifically to model linguistic abilities. By using concept-models with multiple sensorimotor modalities, a MFT system can integrate language-specific signals with other internal cognitive representations. The general aim of this project is to integrate language and cognitive capabilities in cognitive systems through the combination of grounded adaptive agent and MFT techniques. This will be achieved through the following objectives: 1. To adapt the MFT algorithm for the acquisition of linguistic, cognitive and sensorimotor abilities in adaptive agents 2. To design and implement a computer simulator for linguistic agents with MFT controller 3. To execute a series of simulation experiments on the integration of language and cognitive abilities in collaborative tasks (e.g. object manipulation and navigation tasks) 4. To do further simulation aiming at the scaling up of the agents' lexicon in terms of high number of lexical entries and types of syntactic categories						
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<p>4. To do further simulation aiming at the scaling up of the agents' lexicon in terms of high number of lexical entries and types of syntactic categories</p>	<p>4.1 Initial simulations on the scaling up of MFT to the classification of thousands of objects and models have demonstrated the feasibility of the algorithm against combinatorial complexity.</p> <p>4.2 Results on the scale up of the original MFT algorithm are available on the project website http://www.tech.plym.ac.uk/vadim/Results1.htm</p> <p>4.3 Some scale up simulations on the multi-feature MFT algorithm were included in the paper submitted to the ICANN2006 conference.</p> <p>4.4 New simulation experiments on the classification and categorization of actions and the building of sensorimotor concept-models. Use of a set of 112 actions resembling the semaphore flag signaling system. Results demonstrate that the MFT algorithm can easily scale up to the use of numerous actions/words with minimal parameter tuning (see below report on new simulation results)</p> <p>4.5 New simulations on the extension of the MFT algorithm to enable agents to learn a lexical item to name each of the 122 actions. After performing the action, the agents learn to describe each action using three-letter words Consonant-Vowel-Consonant). These simulations show that agents are able to learn a lexicon to describe these objects/actions through a process of cultural learning (see below report on new simulation results)</p> <p>4.6 New simulations on acquisition of composite actions. First the agent learns a series of basic actions and their basic names. Subsequently, the agent is able to successfully combine basic actions into higher order concepts through the combination of the action words, as in a simplified grammar. (see below report on new simulation results)</p> <p>4.7 Plan for future language-cognition integration experiments with real robot. Cangelosi and Tikhanoff are currently in discussion with Professor Giulio Sandini (Italian Institute of Technology, Genoa) to implement some of the above experiments with one of the humanoid robotic platform available at the Italian Institute of Technology. Tikhanoff is expected to spend a few months in Genoa to work on this in the period February-June 2006.</p>
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ADDITIONAL ACTIVITIES BETWEEN NOVEMBER 2005 - MARCH 2006

1. Literature review for PhD and project

Tikhanoff, under the supervision of Cangelosi, started in November 2005 the theoretical preparatory work for the project. His literature review has focused on the following topics: (a) action and language integration; (b) computational models of the evolution and acquisition of language; (c) modelling field theory for cognitive studies; (d) human-robot interaction and communication.

2. Organisation of Special session on "Modelling Language Acquisition and Evolution" at the IJCNN06 conference.

Cangelosi was the chair of the Special Session on "Modelling Language Acquisition and Evolution" held on July 2006 at the IJCNN2006 conference. The session was organized in collaboration with Dr. Leonid Perlovsky and Prof. Jose' Fernando Fontanari. The special session consisted of 6 papers refereed through the standard IJCNN review procedure.

3. Site visit by Dr. Paul Losiewicz, EOARD London

On 12-13 January 2006 we had a site visit by Dr. Losiewicz (see enclosed agenda). During this visit we presented the early work on the project. Dr. Losiewicz also met with various research groups active in our Faculty. We also discussed possible ideas and topics for follow-on research, which will be discussed soon between Dr. Cangelosi and Dr. Losiewicz.

4. Grant meeting and workshop in Joao Pessoa, Brazil (17-24 February, 2006)

During the week starting on February 17 we had a very useful workshop amongst the Plymouth Team (Cangelosi and Tikhanoff), Dr. Perlovsky (USAF Hanscom, MA) and Prof. Fontanari (University of San Paulo at San Carlos). During the workshop we discussed and developed new versions of the MFT algorithm to deal with multi-feature object representation and to extend the model to deal with word-word and word-object association learning during language acquisition.

5. Webpage for grant

Tikhanoff has designed a web page dedicated to the project. This includes an overview of the project, results of simulations, and publications produced by the team. The grant webpage is available at the following website:
<http://www.tech.plym.ac.uk/vadim/>

ADDITIONAL ACTIVITIES BETWEEN APRIL 2006 - OCTOBER 2006

6. Presentation at AFOSR Workshop At Information Fusion Conference

Professor Cangelosi presented the cognitive robotic model at the AFOSR WORKSHOP, part of the Information Fusion Conference in Florence, July 10-11, 2006. The participation to the AFOSR workshop provided an excellent opportunity to meet with the researchers involved in information fusion, including EOARD contractors from European universities, AFRL researchers, and other U.S. academics involved in AFRL projects and to get an up-to-date overview of current research projects in the different levels of information fusion, including multisensor fusion, situation awareness, distributed intelligent control.

7. Proposal for Special Issue in the journal *IEEE Transactions on Neural Networks*

Cangelosi in collaboration with Dr. Perlovsky and other colleagues have proposed the preparation of a special issue in the journal *IEEE Transactions on Neural Networks*. The topic of the special issue is "Modelling the Mind and Brain". We are currently awaiting for the outcome of our proposal.

8. Grant meetings at Evolang6 Conference in Rome.

On April 12-14, Professor Cangelosi was the Conference Chair of the 6th International Conference on the Evolution of Language (Evolang6), in Rome. Tikhannoff was also involved in the Organising Committee. During the conference we had some grant meetings with Perlovsky and Fontanari to discuss ongoing work on the project and the changed to MFT algorithm for the scaling up experiments.

9. Featuring of research in New Scientist magazine

Following the IJCNN presentation of our paper, Cangelosi was approached by Tom Simonite, a journalist for the New Scientist magazine, for an article on our research. The article "Virtual bots teach each other using wordplay" was published on August 2nd, 2006, in the on-line version of the New Scientist magazine:

<http://www.newscientisttech.com/article.ns?id=dn9652>

10. Interview on BBC Radio

Professor Cangelosi was invited to give a live interview on this work at the BBC Radio Devon Breakfast Show on August 31, 2006. The interview is available on the PI's webpage:

<http://www.tech.plym.ac.uk/soc/staff/angelo/>

11. Featuring of research in Professional Engineering magazine

Last August Professor Cangelosi was also approached by Rebecca Rushmer, a journalist for the Professional Engineering magazine, for an article on this research. We are still waiting to hear about the publication details of the article.

12. Presentation at Science Festival, Genoa (Italy)

Cangelosi has been invited to a conference on "How we lean to speak: Comparing Babies and Machine" at the Science Festival in Genoa, Italy. This will be held on October 30, 2006. Webpage here:

<http://www.festivalscienza.it/it/programma/evento.php?id=153>

13. Interview on Italian RAI Radio

Cangelosi will be interview on the research on robots and language at the program "Radio3 Scienza" of the Italian RAI Radio Channel 3. This will be on the morning of October 30th, 2006.

14. Participation to Summer School in Cognitive Robotics

Tikhannoff was selected and attended the Veni Vidi Vici'06 Robocub summer school in July 2006 (Ventimiglia, Italy).

<http://eris.liralab.it/summerschool/>

During the school he applied a version of the multi-dimensional MFT algorithm on a 23 degree of freedom humanoid robot to successfully achieve categorization of actions.

SCHEUDLE OF REPORTS/DELIVERIES (in bold deliverable between April and October 2006)

Original deliverables	Actual deliverables
INTERMEDIATE REPORT: March 28, 2006 Report on the design of model and preliminary testing and Conference paper submission; Prototype of simulator for robotic experiments on grounding communication in sensorimotor and	See Intermediate report submitted to EOARD in March 2006

<p>cognitive tasks.</p> <p>July 30, 2006: Presentation of work (e.g. IEEE World Congress on Computational Intelligence, Vancouver)</p>	<p>1. Presentation of IJCNN paper at IEEE World Congress on Computational Intelligence, Vancouver, on 16-21 July 2006</p> <p>2. Organization of special session at IJCNN</p>
<p>FINAL REPORT: October 31, 2006:</p> <p>Final report on simulation experiments and preparation of paper for neural network and/or robotics journal (e.g. Neural Computation or IEEE Trans. Neural Networks);</p> <p>Final release of robotic simulator.</p>	<p>A new delivery is the paper that will be presented at the IEEE KIMAS Conference in Boston (April 2007).</p> <p>The report enclosed at the end of this document contains a detailed description of the new experiment on scaling up of lexicon and action repertoire. Some of the results will be included in the KIMAS presentation. The report, together with the other simulation published in the ICANN and IJCNN papers, will constitute the core of the journal paper that is going to be prepared for submission to IEEE Transactions on Neural Networks (possibly as part of the special issue on Mind and Brain that we have proposed to the editor)</p> <p>The simulator for the robotic experiments and the MFT language and action training is available in the grant webpage: http://www.tech.plym.ac.uk/vadim/Images/Results/ODE_MFT.zip</p>

PUBLICATIONS FROM GRANT

Cangelosi A., Tikhanoff V. (2006). Integrating Action and Language in Cognitive Robots: Experiments with Modeling Field Theory. *Fusion 2006 Conference, Satellite EAORD workshop, Firenze*, 10 July 2006

Cangelosi A., Hourdakis E. & Tikhanoff V. (2006). Language acquisition and symbol grounding transfer with neural networks and cognitive robots. *Proceedings of IJCNN2006: 2006 International Joint Conference on Neural Networks*. Vancouver, July 2006.

Tikhanoff V., Fontanari J.F., Cangelosi A. & Perlovsky L.I (2006). Language and cognition integration through modeling field theory: Simulations on category formation for symbol grounding. *ICANN2006 International Conference on Artificial Neural Networks. Athens*, September 2006.

Tikhanoff V., Cangelosi A., Fontanari J.F. & Perlovsky L.I. (2006). Scaling up of action repertoire in linguistic cognitive agents. *KIMAS07: IEEE International Conference on Integration of Knowledge Intensive Multi-Agent Systems, Boston*, April 2007

Tikhanoff V., Cangelosi A., Perlovsky L.I. & Fontanari J.F. (in preparation). Language and cognition in cognitive robots: Experiments on action-language integration. *IEEE Transactions in Neural Networks*.

Report on New Simulations on the Scaling up of lexicon and action repertoire in cognitive agents

Recent research in autonomous cognitive systems has focused on the close integration (grounding) of language with perception and other cognitive capabilities. In this paper we propose the utilization of the Modeling Field Theory (MFT) to deal with the combinatorial complexity problem of language modeling. MFT aims at overcoming such limitations by dynamic logic learning of lower-level signals (e.g., inputs, bottom-up signals) with hierarchies of higher-level concept-models (e.g. internal representations, categories/concepts, top-down signals). This is the case of language, which is characterized by the hierarchical organization of underlying cognitive models.

In this paper we present an integration of the Modeling Field Theory algorithm for the classification of objects with a model of the acquisition of language in cognitive robotics. In new simulations we have applied and extended our previous modified version of the MFT algorithm to deal with the scaling up of the robotic agent's action repertoire. Simulations are divided into two stages. First agents learn to classify 112 different actions inspired by an alphabet system (the semaphore flag signalling system). In the second stage, agents also learn a lexical item to name each action. At this stage the agents will start to describe the action as a "word" comprised of three letters (consonant - vowel - consonant). The outcome of the simulations is that: (i) agents are able to acquire a complex set of actions by building sensorimotor concept-models; (ii) agents are able to learn a lexicon to describe these objects/actions through a process of cultural learning. (iii) agents learn actions as basic gestures in order to generate composite actions.

Introduction

Modeling Field Theory

Modeling Field Theory is based on the principle of associating lower-level signals (e.g., inputs, bottom-up signals) with higher-level concept-models (e.g. internal representations, categories/concepts, top-down signals) avoiding the combinatorial complexity inherent to such a task. This is achieved by using measures of similarity between concept-models and input signals together with a new type of logic, so-called dynamic logic. MFT may be viewed as an unsupervised learning algorithm whereby a series of concept-models adapt to the features of the input stimuli via gradual adjustment dependent on the fuzzy similarity measures.

Modeling Field Theory combines neural architecture with models of objects. For feature-based object classification considered here, each input neuron $i = 1, \dots, N$ encodes feature values O_i (potentially a vector of several features); each neuron i may contain a signal from a real object or from irrelevant context, clutter, or noise. We term the set $O_i, i = 1, \dots, N$ an input neural field: it is a set of bottom-up input signals. Top-down, or priming signal-fields to these neurons are generated by models, $M_k(S_k)$ where we enumerate models by index $k = 1, \dots, M$. Each model is characterized by its parameters S_k , which may also be a vector of several features. In this contribution we will consider the simplest possible case, in which parameters model represent feature values of object, $M_k(S_k) = S_k$. Interaction between bottom-up and top-down signals is determined by neural weights associating signals and models as follows. We introduce an arbitrary similarity measure $l(i|k)$ between bottom-up signals O_i and top-down signals S_k [see equation (2)], and define the neural weights by

$$f(k|i) = l(i|k) / \sum_k l(i|k) \quad (1)$$

These weights are functions of the model parameters S_k , which in turn are dynamically adjusted so as to maximize the overall similarity between object and models. This formulation sets MFT apart from many other neural networks.

The model

We consider the problem of categorizing N objects $i = 1, \dots, N$, each of which characterized by d features $e = 1, \dots, d$. These features are represented by real numbers $O_{ie} \in (0,1)$ - the input signals - as described before. Accordingly, we assume that there are M d -dimensional concept-models $k = 1, \dots, M$ described by real-valued fields S_{ke} , with $e = 1, \dots, d$ as before, that should

match the object features O_{ie} . Since each feature represents a different property of the object as, for instance, color, smell, texture, height, etc. and each concept-model component is associated to a sensor sensitive to only one of those properties, we must, of course, seek for matches between the same component of objects and concept-models. Hence it is natural to define the following partial similarity measure between object i and concept k

$$l(i|k) = \prod_{e=1}^d (2\pi\sigma_{ke}^2)^{-1/2} \exp\left[-(S_{ke} - O_{ie})^2/2\sigma_{ke}^2\right] \quad (2)$$

where, at this stage, the fuzziness σ_{ke} is

a parameter given *a priori*. The goal is to find an assignment between models and objects such that the global similarity

$$L = \sum_i \log \sum_k l(i|k) \quad (3)$$

is maximized. This maximization can be achieved using the MFT mechanism of concept formation which is based on the following dynamics for the modeling field components

$$dS_{ke}/dt = \sum_i f(k|i) [\partial \log l(i|k) / \partial S_{ke}], \quad (4)$$

which, using the similarity (1), becomes

$$dS_{ke}/dt = - \sum_i f(k|i) (S_{ke} - O_{ie}) / \sigma_{ke}^2. \quad (5)$$

Here the fuzzy association variables $f(k|i)$ are the neural weights defined in equation (1) and give a measure of the correspondence between object i and concept k relative to all other concepts k' . These fuzzy associations are responsible for the coupling of the equations for the different modeling fields and, even more importantly for our purposes, for the coupling of the distinct components of a same field. In this sense, the categorization of multi-dimensional objects is not a straightforward extension of the one-dimensional case because new dimensions should be associated with the appropriate models. This nontrivial interplay between the field components will become clearer in the discussion of the simulation results.

It can be shown that the dynamics (4) always converges to a (possibly local) maximum of the similarity L [14], but by properly adjusting the fuzziness σ_{ke} the global maximum often can be attained. A salient feature of dynamic logic is a match between parameter uncertainty and fuzziness of similarity. In what follows we decrease the fuzziness during the time evolution of the modeling fields according to the following prescription

$$\sigma_{ke}^2(t) = \sigma_a^2 \exp(-\alpha t) + \sigma_b^2 \quad (6)$$

with $\alpha = 5 \times 10^{-4}$, $\sigma_a = 1$ and $\sigma_b = 0.03$. Unless stated otherwise, these are the parameters we will use in the forthcoming analysis.

Simulations

In this section we will report results from 3 simulations. Initially they will be aimed at a simple scaling up of the agent's action repertoire using multi-dimension features. In the second simulation we will demonstrate the correct classification of the input object though the dynamic introduction of the lexicon feature. The third simulation will concentrate on breaking down the actions into basic gestures in order to generate composite actions.

To facilitate the presentation of the results, we will interpret both the object feature values and the modeling fields as d -dimensional vectors and follow the time evolution of the corresponding vector length

$$S_k = \sqrt{\sum_{e=1}^d (S_{ke})^2} / d,$$

which should then match the object length $O_i = \sqrt{\sum_{e=1}^d (O_{ie})^2} / d$.

Simulation I: Classification and categorization of actions / building sensorimotor concept-models

Let's first consider having 112 different actions, some inspired by an alphabet system (the semaphore flag signalling system) see figure 2. We have collected data on the posture of robots using 6 features. The object input data consist of the 6 angles of each, left arm and right arm joints. (Shoulder, upper arm and elbow) The agents first have to learn to classify these actions; at this stage we are using a multi-dimensional MFT algorithm with 112 fields randomly initialized. Figure 1 shows that the model is able to correctly identify the different actions. Although the simulation initially dealt with 112 actions the MFT algorithm was able to categorize to approximately 95% successful matching. Therefore there was a slight reduction in the number of completed actions. Figure 3 shows our system consisting of two simulated agents (teacher and learner) embedded within a virtual simulated environment (Using Open Dynamic Engine).

Classification and categorization of actions

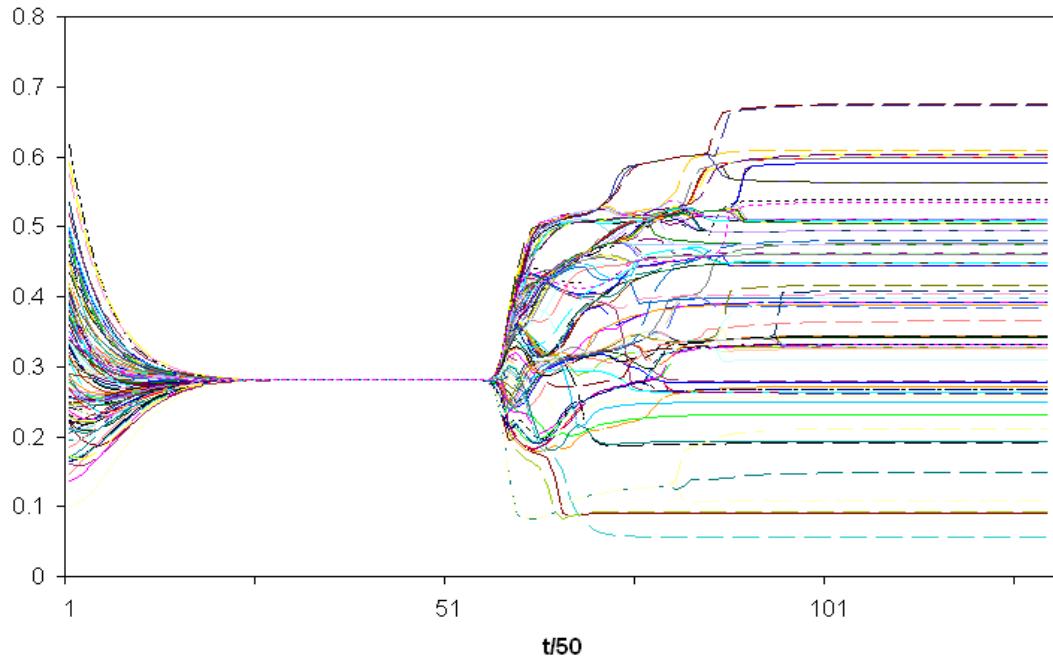


Figure 1: Time evolution of the fields with 6 features being used as input: 112 different actions.

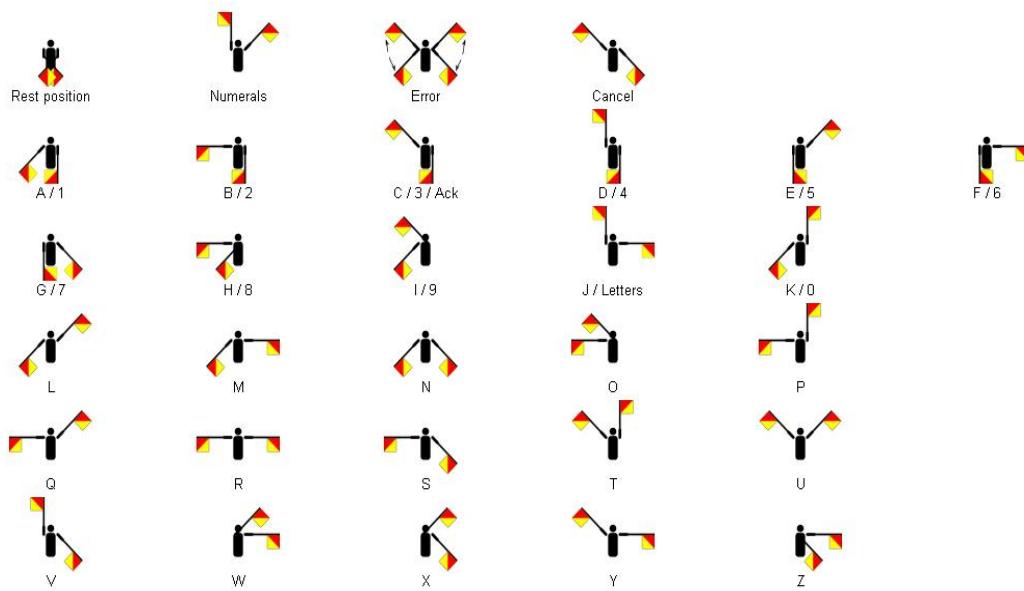


Figure 2: Few examples of type of behaviour used for the classification and categorization of actions. (here the semaphore alphabet)

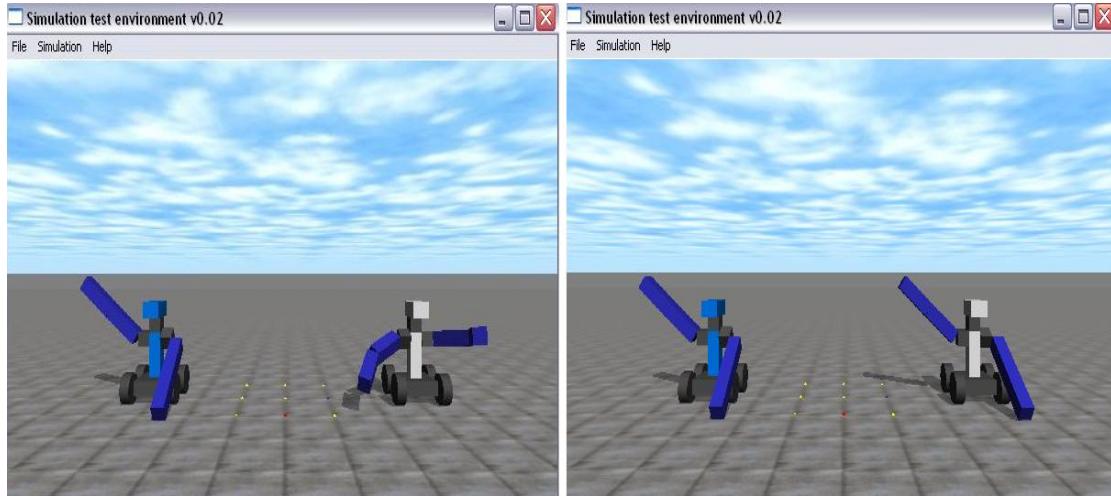


Figure 3: Teacher and learner before (left) and after (right) the action is learnt.

Simulation II: Incremental Feature – lexicon acquisition

In the first simulation we have proposed the use of the multi-dimensional MFT in order to categorize 112 different actions. At this stage we wanted to explore the integration of language and cognition in cognitive robotic studies. Here we extend the multi-dimensional MFT algorithm, used in Simulation 1, to enable the agents to learn a lexical item to name each previous action. After performing the action, the agents will start to describe this action as three letter word. (consonant – vowel – consonant) see example table 1. Each word is unique to the action performed. This phonetic feature is dynamically added immediately after the action. At timestep 12500, (half of the training time) both features are considered when computing the fuzzy similarities. From timestep 12500, the dynamics of the σ_2 fuzziness value is initialized, following equation (6), whilst σ_1 continues its decrease pattern started at timestep 0. Results in figure 4 show that the model is able to categorize an action and assign a ‘word’ to this action.

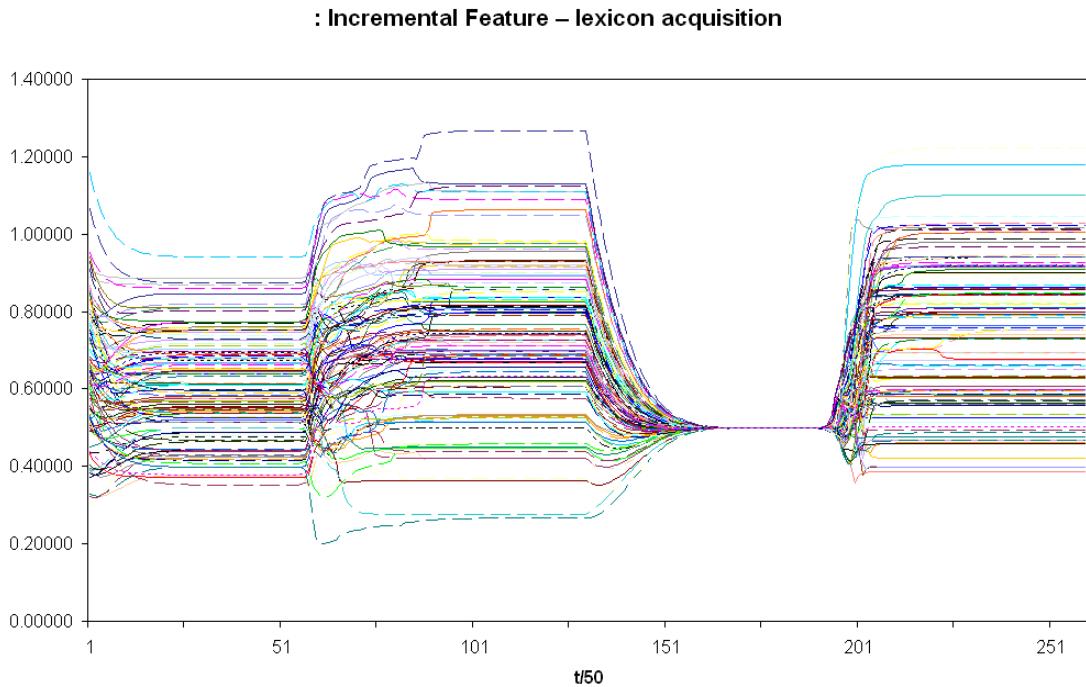


Figure 4: Time evolution of the fields using as input the action and phonetic feature: 112 different actions + 112 words

Actions	Words	Actions	Words	Actions	Words	Actions	Words
1	XUS	29	WED	57	LAC	85	KUN
2	GAP	30	JIL	58	BIF	86	BAM
3	HES	31	SAK	59	FUF	87	TOQ
4	LET	32	BAR	60	HOR	88	NOK
5	PAQ	33	JOC	61	QEB	89	TIL
6	PAL	34	FUV	62	WAH	90	HAW
7	VEH	35	MEL	63	SUD	91	JOJ
8	WIG	36	JAX	64	KAW	92	WOT
9	FUH	37	JAS	65	SAV	93	REW
10	TEP	38	VUS	66	QEQ	94	FUN
11	LUT	39	KEK	67	GES	95	QIH
12	COF	40	MIQ	68	WEJ	96	KUM
13	QUT	41	PAJ	69	KEJ	97	VEF
14	TUW	42	DOJ	70	LUC	98	NUH
15	REV	43	HER	71	KAC	99	GAC
16	QER	44	SAR	72	GUQ	100	KAC
17	BIJ	45	TOD	73	PUB	101	GUG
18	QUR	46	COC	74	RIV	102	QEJ
19	QUX	47	KAH	75	DEM	103	FUG
20	XAM	48	BIG	76	BER	104	KOG
21	BOX	49	QUW	77	WIP	105	VEX
22	QIH	50	PIM	78	PUP	106	WAK
23	PUV	51	DET	79	SIK	107	WOW
24	FAC	52	FUJ	80	XIT	108	BER
25	SIL	53	MIK	81	VEN	109	CEB
26	TAX	54	MEG	82	FIP	110	TOK
27	HUT	55	RAQ	83	SIC	111	TES
28	DOK	56	MAK	84	WUW	112	LOP

Table 1: Table containing examples of words generated by the agents for a specific action

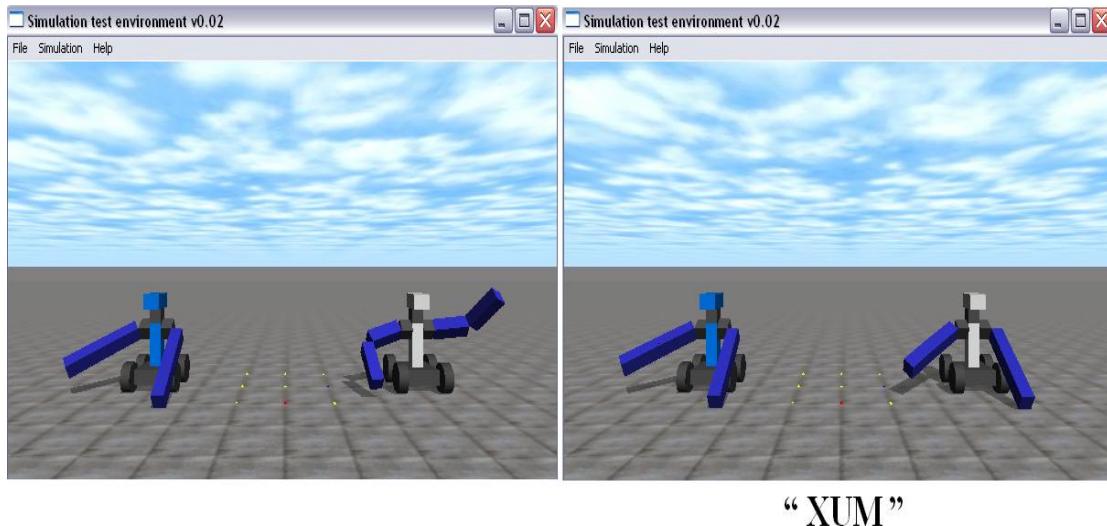


Figure 5: Teacher and learner before action is learnt and after with the addition of the ‘word’. For visualization purposes, the word is added on the image.

Simulation III: Progressive learning of basic gestures into composite actions

Previous simulations consisted of learning actions or a combination of actions and words. In this final simulation we are taking a step backwards in the categorization of actions. We are breaking down the action into basic gestures. Before learning a completed action we are interested in the systematic breakdown of actions into individual gestures, that is to say for example a

two-handed action would be broken down into two single handed-actions and analyzed as individual steps in the process of a compound action. As an extension to the previous simulations, each feature is added dynamically. Firstly the simulation starts with the left-handed action. At timestep 10000 (1/3rd of the simulation) we consider the right-handed action, using the same dynamics of the fuzziness values as for simulation 2 and finally at timestep 20000 we consider the phonetic feature. Figure 6 shows that the model is able to dynamically adapt to compound action associated with the word generation.

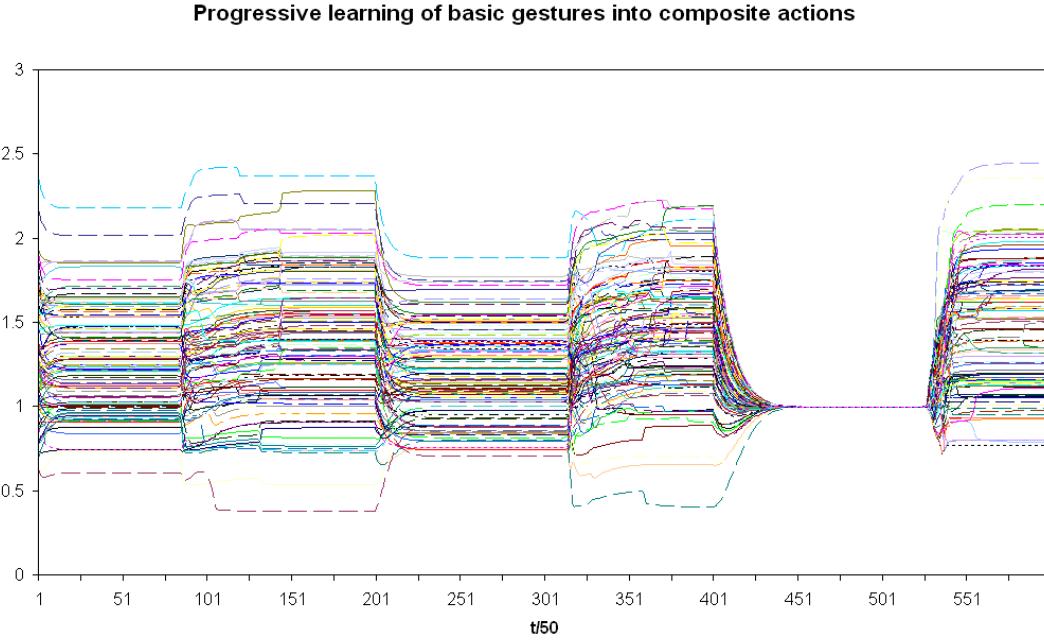


Figure 6: Time evolution of the fields using as input the composite action and phonetic feature: 112 different composite actions + 112 words

Discussion and conclusion

In this paper we present an integration of the Modeling Field Theory algorithm for the classification of objects with a model of the acquisition of language in cognitive robotics. In new simulations we have applied and extended our previous modified version of the MFT algorithm to deal with the scaling up of the robotic agent's action repertoire. The various simulations showed that (i) agents are able to acquire a complex set of actions by building sensorimotor concept-models; (ii) agents are able to learn a lexicon to describe these objects/actions through a process of cultural learning. (iii) agents learn actions as basic gestures in order to generate composite actions.